vessel 200 can be seen. The elements shown therein are designed to seal the interior of the pressure vessel 200 against water, while at the same time provide an entry/exit for the power cable and optical fibers (not shown in this figure). The pressure vessel assembly includes a C-ring 210, a pressure vessel endcap 212 with at least one gasket 214, a breech ring 216 having engagement elements 230, a bell housing 218 having engagement elements 236 and a gimbal 220. For more details regarding an exemplary pressure vessel which can be used in conjunction with repeaters according to the present invention, the interested reader is directed to commonly assigned, copending U.S. Patent Application Serial No. 09/969,152, entitled "Repeaters with Pressure Vessels Having Breech Joints", to Perry Pitrone et al., filed on October 3, 2001, the disclosure of which is incorporated here by reference.

[0051] Manufacturing of the aforedescribed elements of pressure vessel assemblies according to the present invention can be accomplished in a number of different ways. For example, the pressure vessel 200 and endcap 212 can be forged and post machined. Since no flanges are provided for endcap attachment, extrusions and rolled rings can be used for the cylindrical section from which the pressure vessel is machined, which reduces machining waste associated with flanged forged pressure vessels. The bell housing 218 can be centrifugally cast and post machined. The breech ring 216 can be machined from plate metal stock.

[0052] As mentioned above, a dielectric layer 202 can be inserted between the pressure vessel 200 and inner frame structure 203 to protect the optical/electrical circuitry held in the frame structure against the very large amount of power carried by the power cable to supply each of the repeaters 16. Applicants believe that, depending upon the length of the system, distance between repeaters, power consumption of each repeater and other design variables, it will be desirable to provide more than 40kV, possibly as much as 50-60kV, to the power cable. Accordingly, with a safety margin of, for example, 50% it will be desirable to provide a dielectric layer 202 that has a breakdown voltage of greater than 40kV and, more preferably greater than 75kV, to protect the components held in the inner frame structure 203.

[0053] However, the dielectric layer 202 should also have certain other characteristics. For example, the dielectric layer 202 should fit within an allocated volume. As

13	1429.50	34.20
14	1449.00	42.00
15	1498.00	18.20
16	1412.50	45.10
17	1424.50	43.30
18	1439.50	38.30
19	1457.00	42.00
20	1506.00	28.10

Table 2

[0069] The paired pump lasers provide redundancy such that if one of the lasers in a particular laser pair becomes inoperative, then the output power of the remaining laser can be increased so that that the overall gain profile is not substantially affected. Between each pump laser 314 and its respective pump radiation combiner 312, a fiber Bragg grating (not shown) can be inserted as a wavelength locker that locks the radiation output from its associated laser 314 to the desired wavelength.

[0070] Each of the four pump radiation combiners 312 combines the radiation at the wavelengths of the set of wavelengths of its respective pump radiation source 310. Each pump radiation source 310 and corresponding pump radiation combiner 312 can be associated with a line assembly as described below. The combination of pump laser outputs within each line assembly can be accomplished in stages by providing a number of pump radiation combiner components within each unit 312. For example, each pair of pump lasers 314 within a pump radiation source 310 can initially be combined using a pump beam combiner (not shown) component. The pump beam combiners combine optical energy from each pair of pump lasers in a manner which depolarizes the resulting pump output. Various examples of techniques for combining the outputs of pump lasers to generated depolarized pump energy are described in co-pending, commonly assigned U.S. Provisional Patent Application Serial No. 60/326,451 ___________, entitled "Depolarizer for Multiplexed Arbitrarily Polarized Lasers", to Nandakumar Ramanujam et al., filed on October 3, 2001, the disclosure of which is incorporated here by reference.

[0071] The outputs of pairs of pump beam combiners can then be combined by input to a pump wavelength combiner component (not shown), which process can be continued

ahr

until all of the pump laser outputs within a line assembly are combined. Other examples of pump radiation combining can be found in co-pending, commonly assigned U.S. Patent Application Serial No. 09/838,218, entitled "A Pump Assembly Employing Coupled Radiation Sources for Multiple Fibers", to William Shieh et al., filed on April 20, 2001, the disclosure of which is incorporated here by reference.

[0072] The four pump radiation combiner outputs are optically coupled to a 4x4 coupler 318, which combines the outputs of the various pump lasers from each of, in this example, four line assemblies. The 4x4 coupler 318 outputs a set of pump signals via the four coupler outputs 320 to be coupled with the optical data signals transmitted on each of the fibers 326. Because the 4x4 coupler 318 combines the coupled radiation profiles input into the 4x4 coupler, the output from each of the four coupler outputs 320 has the spectral shape of the combined coupled radiation profiles. Therefore, each of the four pump radiation profiles has a contribution from all of the individual wavelengths of four pump radiation sources 310. This enables the pump lasers 316 on each line assembly to be shared among all four line assemblies in the line quad and to provide pumping power to all four of the optical fibers associated therewith.

[0073] An example of a balanced 4x4 coupler which can be used as 4x4 coupler 318 is provided in Figure 12, however the interested reader is referred to co-pending, commonly assigned U.S. Patent Application Serial No. 09/969,142, entitled "Balanced Coupler for Radiation Sources", to William Shieh et al., filed on October 3, 2001, the disclosure of which is incorporated here by reference, for more detail. In Figure 12, it can be seen that the 4x4 coupler 318 can be implemented in two sections 350 and 352, each of which can be disposed within a different line assembly (described below). Since these two sections are identical, only section 350 is described herein. The outputs of two of the pump radiation combiner units 312 are input into a first 2x2 coupler 360, one of the outputs of 2x2 coupler 360 is passed directly to a second 2x2 coupler 362, while the other output is first passed through fiber section 364 (e.g., 10m of single mode fiber). One of the outputs of 2x2 coupler 362 is passed to section 352 of the 4x4 coupler, while the other output is passed to 2x2 coupler 366. 2x2 coupler 366 accepts as its other input the corresponding feed from 2x2 coupler 368 of section 352. One output of 2x2 coupler stage 366 is passed directly to the final 2x2 coupler stage 370,

while the other output of 2x2 coupler stage 366 is first passed through fiber loop 372 (e.g., 60m of single mode fiber) prior to being input to 2x2 coupler 370. The two outputs of section 350 are passed to respective pump signal combiners 322 to couple the pump radiation energy with the fibers 326.

[0074] Specifically, an optical signal 324 propagates along a respective fiber 326 to a respective pump-signal combiner 322, where it is combined with a respective pump radiation profile. The pump radiation profile radiation counterpropagates with respect to a respective optical signal 324 and amplifies the signal 324 in the fiber 326. The pump assembly 301 also includes a number of other signal path processing devices, e.g., one or more gain shaping filters 330 and isolators 332 and 334.

[0075] The signal path processing devices may also include an additional coupler (not shown) for coupling a co-propagating pump radiation profile to the optical data signals 324. Co-propagating pump radiation can be used to amplify the optical data signal as it leaves a repeater 16 so that launch power can be reduced. If so-called forward pumping is employed in addition to or in place of contrapropagating (backward) pumping, then one or more co-propagating pump lasers can be added to one or more of the pump radiation sources 310. These co-propagating lasers can also be shared among the line assemblies as described, for example, in co-pending, commonly assigned, U.S. Patent Application Serial No. 09/865,440, entitled "Shared Forward Pumping in Coupled Line Pair Architecture", to Thomas Clark et al., filed on May 29, 2001, the disclosure of which is incorporated here by reference, and by providing a second 4x4 coupler (not shown) to combine the forward pump outputs from each of the line assemblies.

[0076] As mentioned above, in addition to the pump lasers 314 themselves, the repeater also includes laser driver circuitry 460, monitoring and control circuitry 462, and power supply circuitry 464 as generally shown in Figure 13. Therein, a shunt regulator 466 shunts a predetermined line voltage to a repeater 16 from power cable 468. DC-DC converters 464 downconvert the line voltage to a voltage usable by the monitor & control electronics 462 and laser current drivers 460. The monitoring and control circuitry 462 provides the capability for the terminals and repeaters to exchange maintenance and control information over a communication channel. This communication channel can be implemented by modulation of the communication

envelope within which the high data rate WDM channels are carried or by providing a separate wavelength channel for this purpose. For more details regarding exemplary monitoring and control circuitry 462, the interested reader is referred to co-pending, commonly assigned U.S Patent Application Serial No. 09/927,439, entitled "Redundant Repeater Monitoring Architecture", to John Mellert et al., filed on August 13, 2001, the disclosure of which is incorporated here by reference.

[0077] The monitoring and control circuitry 462 consumes a small percentage of the total power consumed by a high power repeater 16 according to the present invention. Together the pump lasers 314 and the laser current drivers 460 consume the majority of the repeater's power. The total power consumed by high power, Raman amplification repeaters according to the present invention will depend upon many variables including the number of pump lasers used in each repeater and the anticipated spacing between repeaters 16 in the optical communication system (generally, greater spacing requires greater pump power). Another consideration in the total repeater power budget is the manner in which the laser current drivers provide current to each pump laser pair. One possibility is to provide a fixed supply voltage from which each laser current driver provides each pump laser pair with sufficient drive current to generate a predetermined optical output power from the laser pair. This approach, however, is not the most power efficient approach, because each pump laser can require a different amount of drive current to generate the predetermined optical output power. This phenomenon, and exemplary laser current drive circuits for more efficiently providing drive current to the large number of pump lasers found in high power repeaters according to the present invention, are described in more detail in co-pending, commonly assigned U.S. Patent Application Serial No. 09/969,154, entitled "Efficient Laser Current Drivers" to Ronald E. Johnson, filed on October 3, 2001, the disclosure of which is incorporated here by reference. To summarize some of the results found in this patent application, Table 3 provides information regarding an exemplary 24 laser pair repeater intended to operate in a system having repeaters 16 spaced approximately 60 km apart.